MULTIMEDIA UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 1, 2019/2020**

## ENT4066 – NANOELECTRONICS MATERIALS AND DEVICES
(NE)

18 OCTOBER 2019
9.00 a.m. – 11.00 a.m.
(2 Hours)

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**INSTRUCTION TO STUDENTS**

1. This examination paper consists of 5 pages with 4 questions only.

2. Attempt **ALL FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

## QUESTION 1

(a) (i) Briefly explain the phenomenon in nanoscale particles rials for each of the statements in **Table Q1(a)** below:

**Table Q1(a)**

| Statement about Nanoscale particles | Explain why |
|---|---|
| Maximize possible reactivity | |
| Lower melting temparature | |
| Relatively larger surface area | |

[6 marks]

(ii) What are the **TWO** (2) principal factors cause the properties of nanomaterials to differ significantly from bulk materials. [2 marks]

(iii) The magnetic properties of nanoparticles depend on the size, shape, and composition. Explain **Superparamagnetism**, which appears in small ferromagnetic nanoparticles. [2 marks]

(b) (i) Briefly explain why energy bandgap of nanoparticle change with the change in the particle size. [2 marks]

(ii) What is "Exciton Bohr Radius"? Why "Excitation Bohr Radius" is different in quantum dot nanomaterial? [1+ 2 marks]

(c) (i) By means of simple diagrams, compare the current-voltage characteristic of a normal capacitor and a nano-capacitor. [2 marks]

(ii) Define the capacitance-voltage requirement for electron tunnelling. [1 mark]

Compare the voltages for a millimetre-capacitor with C = $1.1\times10^{-13}$ F, and nano-capacitor with C = $1.1\times10^{-19}$ F. Why is Coulomb blockade not observed in macro-sized circuit? [2+1 marks]

(iii) Temperature plays an important role in Coulomb blockade phenomenon, which requires the charging energy of nano-capacitor to be greater than the thermal energy.

Derive the thermal condition for Coulomb blockade, and calculate the temperature for above capacitances, $1.1\times10^{-13}$ F and $5.7\times10^{-17}$ F.
Given that Boltzmann constant $k_B = 1.381\times10^{-23}$ J/K, electron charge $1.602\times10^{-19}$ C.
[2+2 marks]

**Continued.....**

## QUESTION 2

(a) Briefly explain **THREE (3)** differences between homogenous and heterogeneous nucleation. [3 marks]

(b) Explain with suitable diagram the mechanism of uniform particles synthesis as a result of *aggregation* of much smaller subunits rather than continuous growth by diffusion. [4 marks]

(c) Consider (15, 5) is a single-wall carbon nanotubes (SWCNT). If chiral angle (θ) and diameter (d) of a carbon nanotube (CNT) is given by:

$$\theta = \tan^{-1}\left(\frac{\sqrt{3}m}{m+2n}\right)$$

$$d = \frac{\sqrt{3}a_{cc}\sqrt{m^2+n^2+mn}}{\pi}$$

respectively, where $m$ and $n$ are integers governing the chiral vector C, and $a_{cc} = 0.142$ nm is the carbon bond length. If unzipping the SWCNT form a 1 μm Graphene sheet,

(i) Calculate the chiral angle and diameter of the SWCNT. [4 marks]
(ii) Is this a metallic or semiconductor type of CNT? [1 mark]

(d) With the aid of diagram explain the "Density of State" (DOS) of metallic and semiconducting carbon nanotubes (CNT). [4 marks]

(e) **Figure Q2(e)** shows a Kataura plot for CNTs.

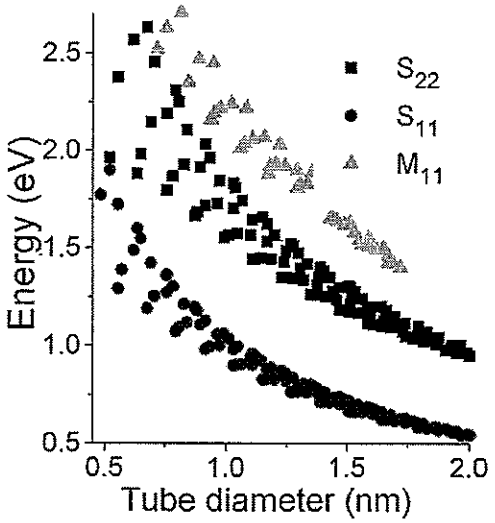


**Figure Q2(e)**

(i) Explain briefly what is Kataura plot. [2 marks]

(ii) By means of energy band structures as a function of density of states, explain what are $S_{11}$, $S_{22}$ and $M_{11}$. [2+2 marks]

(iii) Explain why $S_{11}$, $S_{22}$ and $M_{11}$ curves are not smooth. [3 marks]

**Continued.....**

## QUESTION 3

(a) What are the **THREE** (3) different types of scaling rules applicable on metal-oxide-semiconductor field-effect transistor (MOSFET)? Explain why these scaling rules are significant.

[4 marks]

(b) Plasma enhanced chemical vapour deposition (PECVD) is a particular method to deposit carbon nanotube (CNT). With the aid of diagram, write a short note about PECVD deposition of CNT on any substrate.

[6 marks]

(c) An N-channel silicon MOSFET with 9 nm-thick ($t_{ox}$) oxide has channel width ($Z$) of 700 nm, channel length ($L$) of 450 nm. Given that $V_T = 0.313$ V, $E = 1\times10^{-4}$ V/cm, $\varepsilon_i = 3.9$ and $\varepsilon_o = 8.85\times10^{-14}$ F/cm.

(i) Based on the ideal constant electric field scaling scheme, the channel length of the N-MOSFET is scaled down to 75 nm. Calculate the corresponding values of insulator capacitance ($C_i'$), threshold voltage ($V_T'$) and electric field ($E'$).

[3 marks]

(ii) An NMOS transistor has the following parameters: z = 10 μm, L = 1 μm, and $t_{ox}$ = 250 Å, $N_a = 5\times10^{-15}$ cm$^{-3}$, and applied voltage of 3 V. If the device is to be scaled constant-field scaling, determine the new device parameter for scaling factor of 0.7.

[5 marks]

(d) (i) Sketch the schematic structures of partially-depleted (PD) and fully-depleted (FD) silicon-on-insulators (SOIs) MOSFETs.

[3 marks]

(ii) Comment on the floating body effect (FBE) in PDSOI and FDSOI respectively.

[4 marks]

**Continued.....**

## QUESTION 4

(a) Resonant tunnelling diode (RTD) is a quantum well structure semiconductor which has been used in various applications.

(i) With the aid of diagrams, explain the operating mechanisms of RTD.

[3 marks]

(ii) Briefly described **THREE** (3) reasons that make RTD devices very attractive.

[3 marks]

(b) (i) Sketch an equivalent single-electron transistor (SET) circuit for a metallic island which is weakly coupled to two thin metallic electrodes (D and S), which act as tunnelling junctions. The voltage drops on the two tunnelling junctions are denoted as $V_D$ and $V_S$.

[3 marks]

(ii) In a nanoelectronic device if e is the charge of electron and $C_{tot}$ is the total capacitance, derive the equation for threshold voltage ($V_{th}$).

[5 marks]

(c) (i) What are the **THREE** (3) important parameters that must be considered while fabricating SET devices.

[3 marks]

(ii) In the fabrication process of SET devices, what are the advantages and disadvantages of atomic force microscopy (AFM) assisted nano-oxidation process.

[2 marks]

(d) Explain how organic field effect transistors (OFETs) open the new era of low cost electronic circuits development.

[3 marks]

(e) Depicts various and explain various geometries of the OFET devices.

[3 marks]

**End of Paper.**